Experiment 17: Kirchhoff's Laws for Circuits

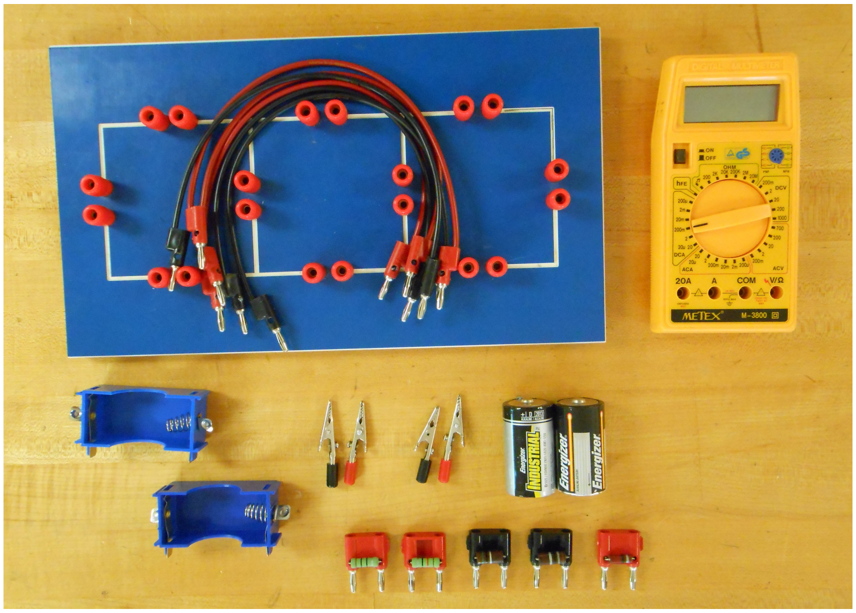

Figure 17.1: Kirchhoff's Law Circuit Board

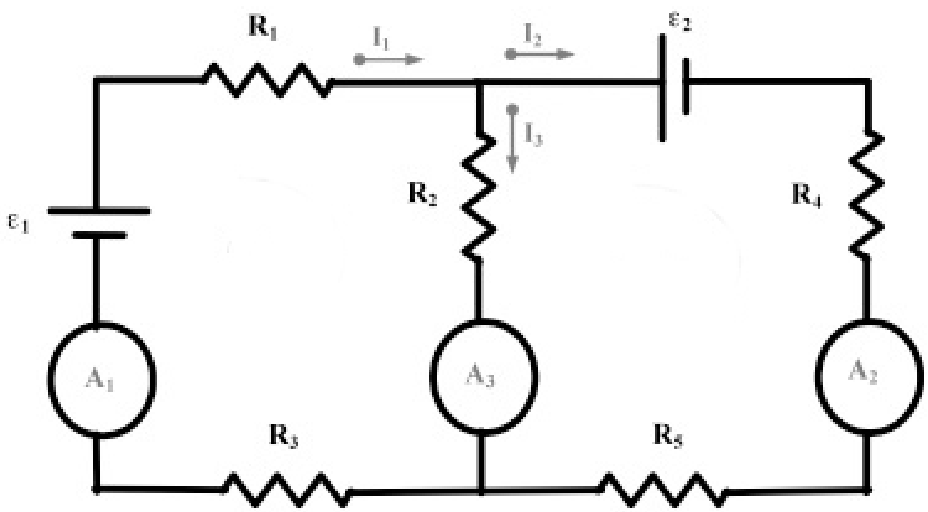

Figure 17.2: Schematic for Kirchhoff's Circuit

EQUIPMENT

(1) Universal Circuit Board
(2) D-Cell Batteries (1.5 V)
(2) Battery Holders
(4) Alligator Clips
(1) DMM

(5) Resistors:
$R_1 = 10\ \Omega$ Resistor
$R_2 = 12\ \Omega$ Resistor
$R_3 = 15\ \Omega$ Resistor
$R_4 = 18\ \Omega$ Resistor
$R_5 = 22\ \Omega$ Resistor

Advance Reading

Text: Kirchhoff's Voltage Law, Kirchhoff's Current Law

Lab Manual: Appendix A: Math Review (solving 3 equations with 3 unknowns)

Objective

The objective of this experiment is to apply Kirchhoff's rules for circuits to a two-loop circuit to determine the three currents in the circuit and the electric potential differences around each loop.

Theory

The two basic laws of electricity that are most useful in analyzing circuits are Kirchhoff's laws for current and voltage.

Kirchhoff's Current Law (The Junction Rule) states that at any junction (node) of a circuit, the algebraic sum of all the currents is zero (sum of the currents entering the junction equals the sum of the currents leaving the junction). In other words, electric charge is conserved.

$$\Sigma I_{in} = \Sigma I_{out} \tag{17.1}$$

Kirchhoff's Voltage Law (The Loop Rule) states that around any closed loop or path in a circuit, the algebraic sum of all electric potential differences is equal to zero.

$$\Sigma V_i = 0 \tag{17.2}$$

To calculate magnitudes of current and voltage in a circuit like Fig. 17.2, you will need to write three equations, making use of both the loop and junction rules. This results in three equations with three unknowns. For this experiment, you will measure ε_i and R_i, then solve for the three currents, I_i.

One might be able to guess the direction of current flow in a circuit, given a circuit such as the one in this experiment. However, as long as the current direction chosen at the beginning is used consistently throughout the calculation, the calculation will be correct. For the purposes of this experiment, all currents will be assumed to be in the direction shown in Fig 17.2. If any current is measured or calculated to be negative, that current actually flows in the opposite direction of what is indicated in Fig 17.2.

Apply the following rules when writing a KVL equation for a loop:

- If a source of *emf* is traversed from $-$ to $+$, the change in potential is $+\varepsilon$; if it is traversed from $+$ to $-$, the change in potential is $-\varepsilon$.
- Current flows from high potential to low potential. A loop crossing a resistor with the current constitutes a negative potential difference. A loop crossing a resistor against the current yields a positive potential difference.

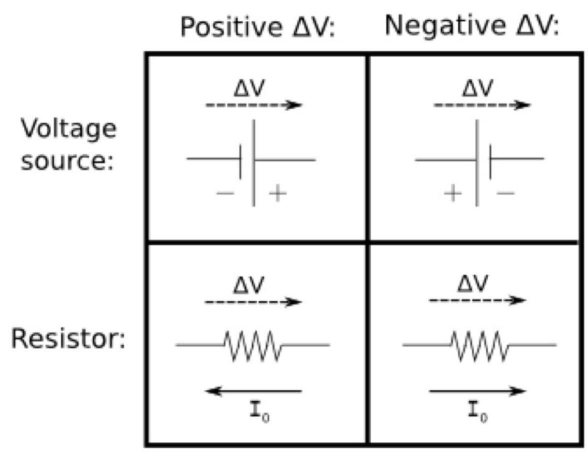

Figure 17.3: Potential Difference Sign Convention

Write and equation relating the currents to each other using the junction rule,. Then write equations for two different loops in terms of electric potential difference.

For example, the equation for the currents in the top center junction in Fig 17.2:

$$i_1 = i_2 + i_3 \tag{17.3}$$

And an equation for the loop consisting of $\varepsilon_1, R_1, R_2, and R_3$ in Fig 17.2 is:

$$\varepsilon_1 - R_1 i_1 - R_2 i_3 - R_3 i_1 = 0 \tag{17.4}$$

Write a similar equation for the loop consisting of $\varepsilon_2, R_4, R_5, and R_2$, then solve this system of three equations for the currents we predict through the three ammeters.

Name: ______________________________

1. Write the equation, then briefly explain: (20 pts ea.)

   (a) Kirchhoff's Voltage Law (KVL)

   (b) Kirchhoff's Current Law (KCL)

2. Consider the circuit shown in Fig. 17.2 and the *Equipment* list on Page 89. Use Kirchhoff's Current Law and Voltage Law to solve for the theoretical currents, $i_1, i_2, and i_3$.

   In performing the experiment, measured values will be used for the emfs and resistances. For the pre-lab, use the nominal values as stated in the *Equipment* list.

   (a) Write the system of three equations. (30 pts)

   (b) Solve for I_1, $I_2, and I_3$ using substitution. (30 pts)

PROCEDURE

PART 1: Loop Method - Calculations

1. Determine the nominal resistance and tolerance of each resistor by reading its color code (Table 15.1, Page 78). They should have the following approximate resistances:

   $R_1 = 10\ \Omega$
   $R_2 = 12\ \Omega$
   $R_3 = 15\ \Omega$
   $R_4 = 18\ \Omega$
   $R_5 = 22\ \Omega$

2. Measure the resistance of each resistor using an ohmmeter.

3. Construct the circuit shown in Fig. 17.2. Do not connect the ammeter.

4. Measure ε of the two batteries using a voltmeter. They should each be at least 1.1 V. Turn off the DMM and disconnect the batteries so they do not drain.

5. Using your knowledge of the loop and junction rules, write three equations relating].

6. Solve these equations by substitution to find the theoretical currents. A negative value simply indicates the current flows in the other direction.

PART 2: Current & Voltage Laws Applied

7. Connect the batteries to the circuit.

8. Measure the current in each of the three branches of the circuit. Refer to Fig. 17.4 for proper ammeter connection technique. Disconnect the batteries and turn off the DMM after measurement.

9. Compare the measured values of current with the calculated values. If they are not approximately equal, check your calculations or retest the circuit.

10. Reconnect the batteries and measure the electric potential across each element of the circuit. Sign and direction are crucial; measure based on the hypothetical directions of current you chose at the beginning. This means the black lead will be placed where current enters the resistor and the red lead will be placed where current leaves the resistor.

Figure 17.4: Ammeter Connection

PART 3: Non-Ideal Voltmeter

At the front of the room, your TA has set up two series circuits. One circuit has two 100 Ω resistors, the other circuit has two 10.0 MΩ resistors. Take your voltmeter to this table. Adjust the power supply on each circuit to 10.0 V.

11. Measure the potential differences across each of the resistors in the 100 Ω circuit. Is the magnitude of their sum equal to the potential difference across the power supply? Show work.

12. Measure the potential difference across each of the resistors in the 10.0 MΩ circuit. Is the magnitude of their sum equal to the potential difference across the power supply? Show work.

QUESTIONS

1. Explain what effect the DMM will have on the circuit when inserted to measure current.
2. Do the values from *Part 2* verify Kirchhoff's Current Law?
3. Do the values from *Part 2* verify Kirchhoff's Voltage Law?
4. Would disconnecting the emf source on the left loop of the circuit, ε_1, affect the current I_2? Calculate what I_2 is for this case. What about I_3.
5. A voltmeter is connected in parallel to a resistor when measuring V_i. Remember that the internal resistance of the DMM, when used as a voltmeter, is approximately 10 MΩ. Calculate $R_{eq}$of the voltmeter connected to a resistor in each circuit of *Part 3*.
6. Use the above information to discuss why the voltage measured across the 10 MΩ resistors did not equal the voltage measured across the power supply.